Refrigerant Flammability:
A New Application of the Opposed-flow Burner

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Due to concerns about the impact of cholorofluorocabrbons (CFCs) on the earth's ozone, new refrigerants are being evaluated by the air-conditioning and refrigerant industry to identify environmentally friendly replacements. These alternative refrigerants are primarily hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs); some of which, because of the additional hydrogen atoms, are flammable. In order to maintain the current requirement of non-flammable refrigerants, optimized mixtures which maximize efficiency while minimizing risk are desired. Current methods of measuring of flammability for weakly flammable refrigerants have a large uncertainty and produce results which require operator interpretation. This work presents an alternative approach with reduced uncertainty and less operator interpretation.

Traditionally, flammability has been measured by devices such as the ASTM E-681 5 liter flask or the Bureau of Mines explosion tube. These devices are operated by igniting a volume of premixed air and fuel, and evaluating whether or not flame propagation successfully occurs. The lean flammability limit is the ratio of fuel and air above which propagation occurs. These devices model a semi-realistic scenario of an ignited gas release. But from a testing perspective, they have significant drawbacks. Both are sensitive to the size, type, and location of the ignition source. In the Bureau of Mines device the difference between upward propagation and downward propagation adds significant ambiguity to the determination of an explicit flammability limit. Another disadvantage is that these test methods are sensitive to the diameter of the test volume. This measurement affects the flame propagation due to cooling at the vessel walls. The overriding disadvantage to these two devices is that it is necessary to use a subjective judgment to evaluate the indistinct boundary between propagation and a non-propagation.

Though the goal of modeling a "realistic" scenario is admirable and for the purpose of risk assessment crucial, in a test where one is measuring a fundamental flammability limit, the result should be independent of the ignition source, the burner or test vessel, and ideally the result should be definitive and independent of the operator's interpretation. When these test methods are used with weakly flammable refrigerants, these difficulties are amplified (in comparison with hydrocarbon fuels) due to the weaker, less repeatable flames.

For more than twenty-five years, the opposed-flow burner has been used by combustion researchers to investigate properties of hydrocarbon flames. The opposed-flow burner used in this work (Figure 1) is comparable. It supports a twin flame between two identical, vertically-aligned, opposed jets of premixed fuel and air. About the jets' stagnation plane, the twin flame is suspended, like two thin luminescent disks. By holding the total volume flow of air and fuel in the jets constant, while reducing the fuel to air ratio, an extinction condition, Φ_x, for a certain flow condition described by the global strain rate, K_g, can be found. A plot of multiple Φ_x for different K_g, as shown in Figure 2 for R-32 (CH_2F_2), defines a lean extinction line. At the intercept, where $K_g = 0$ s^{-1}, the lean flammability limit, $\Phi_0 = 0.78 \pm 0.04$ is defined. By measuring extinction points rather than lack of ignition, and extrapolating to the fundamental limit, the opposed-flow burner eliminates several of the difficulties associated with the more traditional devices.

A description of the opposed-flow burner and approach will be provided and measured lean limits of R-32, methane (CH_4), propane (C_3H_8), and the critical flammability ratio of R-125 (C_2HF_5) in R-32 will be presented.
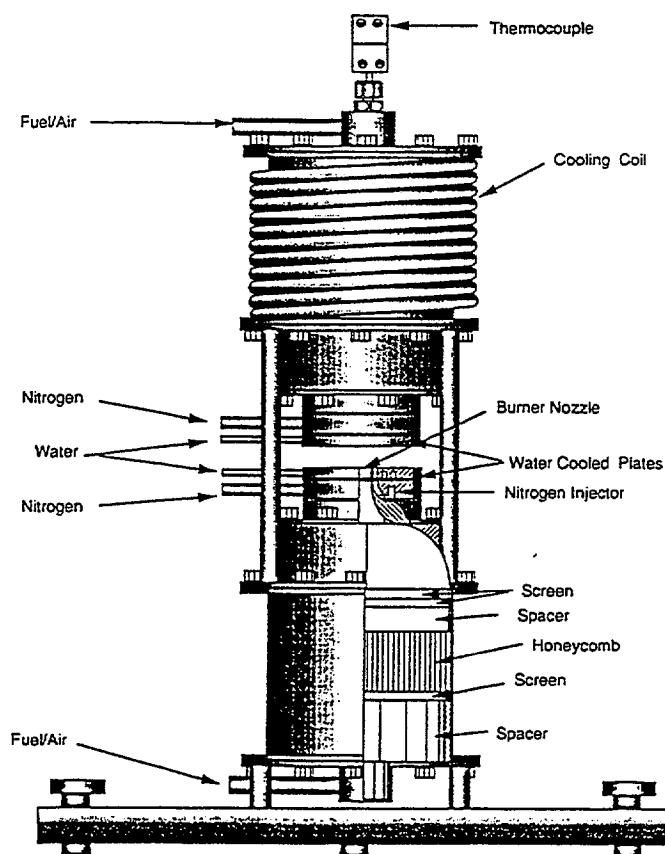
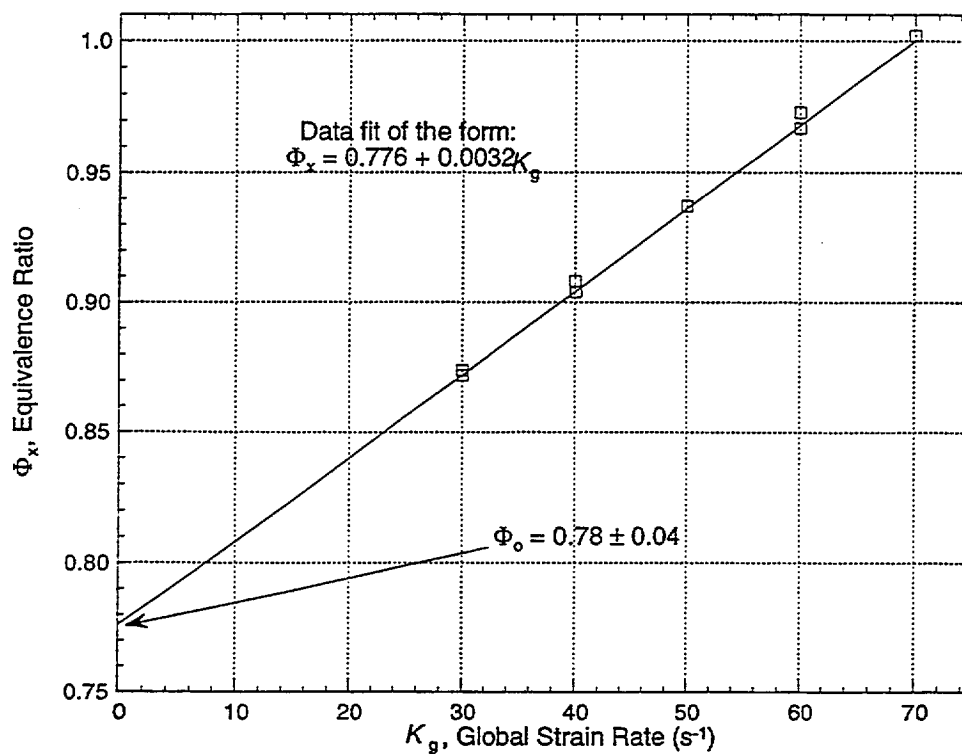Figure 1: Premixed opposed-flow burner.

Figure 2: R-32 (CH_2F_2) extinction points as a function of global strain rates. The intercept defines the lean flammability limit, $\Phi_o = 0.78 \pm 0.04$.